Human On-Line Response to Visual and Motor Target Expansion

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Abstract

The components of graphical user interfaces can be made to dynamically expand as the cursor approaches, providing visually appealing effects. Expansion can be implemented in a variety of ways: in some cases the targets expand visually while maintaining a constant smaller motor-space for selection; and in others both the visual and motor-spaces of the objects are enlarged. Previous research by McGuffin & Balakrishnan [15], and confirmed by Zhai et al. [19], has shown that enlarged motor-space expansion improves acquisition performance. It remains unclear, however, what proportion of the performance improvement is due to the enlarged motor-space, and what to the confirmation of the over-target state provided by visual expansion. We report on two experiments which indicate that for small targets, visual expansion in unaltered motor-space results in similar performance gains to enlarged motor-spaces. These experiments are based on tasks where users are unable to anticipate the behaviour of the targets. Implications for commercial use of visual expansion in unaltered motor-space are discussed.

CR Categories: H5.2 [User Interfaces]: Interaction styles.

Keywords: target acquisition, expanding targets, motor-space, Fitts' Law.

1 Introduction

Cursor-pointing is fundamental to most actions in graphical user interfaces, and extensive research has been dedicated to modelling and improving pointing performance. Recently, several researchers have shown that target acquisition can be improved by dynamically increasing target size as the cursor approaches. Inspired by the MacOS X 'Fisheye' Dock icon-panel (Figure 1), McGuffin & Balakrishnan [15] showed that expanding targets are selected significantly faster than static ones, even when the expansion starts after 90% of the movement towards the target is complete. Zhai et al. [19] replicated McGuffin & Balakrishnan's study with an extra condition that removed the participant's ability to anticipate target expansion. Their results confirmed the performance benefits, even in the absence of anticipation.

These studies and others reported in Related Work investigated performance with targets that visually expand while using continuously enlarged motor-space. Figure 2b shows how discretely arranged targets can allow a larger motor-space than the default visual area of the widget. The primary limitation of enlarged motor-space is that the area around the widget can not be used for other purposes: for example, if a margin-marker was implemented using this technique, then users would be unable to

Figure 1. The MacOS X 'Fisheye' Dock icon-panel.

insert a tab-stop close to the marker because of its enlarged activation area. Somewhat perversely, rather than making targets bigger than they appear, enlarged motor-spaces actually make the targets appear *smaller* than they really are. While there may be valid reasons for deploying the technique, such as reducing clutter on the screen, there are few obvious applications for enlarged motor-space expansion.

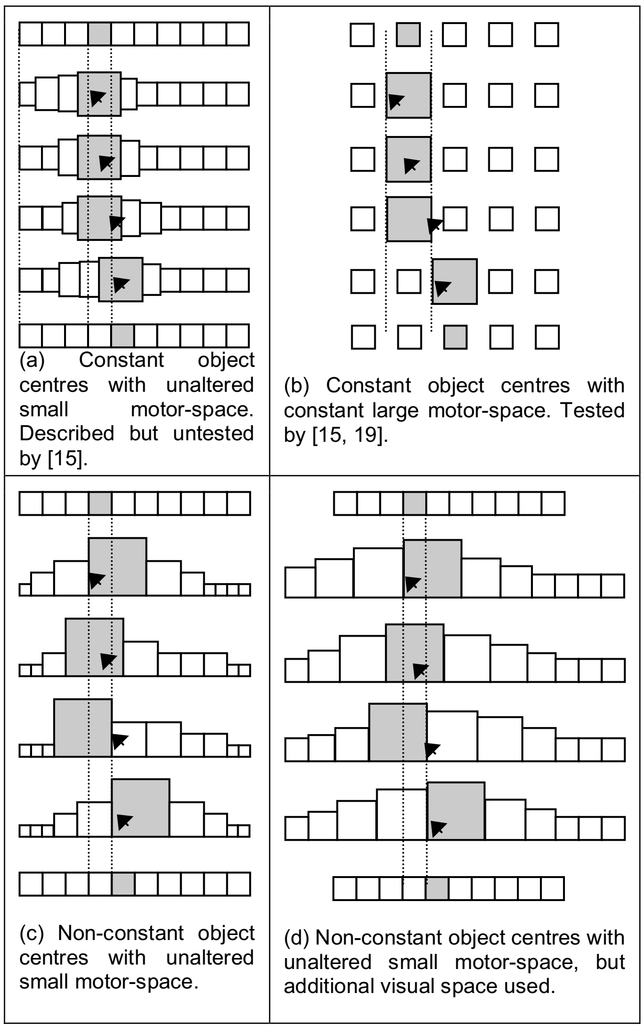
Visual expansion with unaltered motor-space is also possible, as demonstrated by extensive prior work on Fisheye distortion [10, 12, 16]. Figure 2c,d show two implementations of the technique, demonstrating that although the targets appear larger, their motor-space is unchanged. Figure 2d is based on the behaviour of the MacOS X Dock, which expands the visual boundaries of the panel to accommodate the expansion. In theory, implementations based these techniques offer no pointing advantage because the motor-space is no larger than normal. Furthermore, Gutwin [12] showed that fisheyes can harm acquisition because targets move entirely away from the motor-space that activates them, prompting 'hunting effects'. An implementation such as that shown in Figure 2a, however, offers visual expansion in unaltered motor-space, reducing the adverse affects of target displacement because the object-centres remain constant. We are unaware of prior evaluations of this type of target expansion.

Despite its theoretical limitations, it is reasonable to suspect that unaltered motor-space visual expansion of the form shown in Figure 2a will improve acquisition performance, particularly for small targets. This prediction is based on prior research showing that visual feedback enhances target acquisition [2]. When targets are small, such as margin markers, split-pane handles, window borders, etc., traditional methods of mouse-over highlighting are of limited value because the objects consist of few pixels, most of which may be obscured by the cursor—the highlighting may not be noticed. Assuming that visual expansion does improve performance, the question then becomes what proportion of the performance improvements reported with enlarged motor-spaces is due to visual expansion, and what is due to the enlarged motor-space?

This paper reports on two experiments. The first investigates whether unaltered motor-space visual expansion offers larger performance improvements than traditional mouse-over highlighting. The second directly compares target acquisition performance across three conditions: static targets, unaltered motor-space visual expansion, and enlarged motor-space expansion. In these experiments the participants were unable to anticipate whether their targets would expand or not.

The results show that visual expansion offers reliable performance improvements over traditional highlighting. Importantly for the acquisition of small targets, they also suggest that much of the performance improvement previously reported with enlarged motor-space expansion is due to the eased visual confirmation of the mouse-over target state, rather than due to the enlarged motor-space itself.

The paper finishes with a discussion of the implications of the findings for commercial deployment. While some current commercial use of expanding targets can be dismissed as interaction-harming 'eye-candy', it is reasonable to anticipate deployment of expanding targets that are both 'cool' and efficient.



(a) Constant object centres with unaltered small motor-space. Described but untested by [15].

(b) Constant object centres with constant large motor-space. Tested by [15, 19].

(c) Non-constant object centres with unaltered small motor-space.

(d) Non-constant object centres with unaltered small motor-space, but additional visual space used.

Figure 2. Comparing different forms of target expansion.

2 Related Work

As described in the Introduction, this study is primarily motivated by McGuffin & Balakrishnan's [15] and Zhai et al.'s [19] evaluations of expanding targets that use enlarged motor-space. These studies showed that targets that expand in the form illustrated in Figure 2b can be acquired more quickly than static ones. They noted that traditional fisheye views (such as those illustrated in Figures 2c,d) offer no motor-space advantage over static widgets, and they acknowledged Gutwin's [12] finding that fisheye induced object displacement can harm acquisition.

Both McGuffin & Balakrishnan and Zhai et al. attribute the performance enhancements to the increased motor-space. A study by Akamatsu [2], however, suggested that acquisition is improved when static targets change their colour to indicate that the cursor is over the item. Although their results failed to show significant performance gains for highlighting in overall acquisition, the mean selection times were lower when item colouring was enabled, and the participants' dwell time between the cursor entering the item and pressing the mouse button was significantly reduced with visual feedback. Therefore, some proportion of the performance improvement observed by McGuffin & Balakrishnan and by Zhai et al. is most likely explained by the visual confirmation of the mouse-over state rather than by the enlarged motor area.

Fitts' law [9] is a mature theoretical tool for analysing target acquisition [17]. It predicts that the movement time MT taken to select targets is dependent on A, the Amplitude or distance of the movement to the target, and on W, the target width: $MT=a+b\log_2(A/W+1)$, where a and b are empirically derived constants. The logarithmic component of the formula is referred to as the 'index of difficulty' (ID). ISO standard 9241-9 recommends that pointing devices and techniques be evaluated using multi-directional tapping tasks (see Figure 3).

Researchers have experimented with many adaptations to widget and cursor behaviour in order to improve target selection. Balakrishnan [3] provides an excellent review of this research, which includes enlarged cursors [11, 13, 18], dynamic adaptation of control-display gain to create 'sticky' or 'snapping' widgets [1, 4, 6, 8, 14, 18] and haptic devices [2, 7]. While many of these techniques improve the selection of discrete targets (Figure 2b), there has been less success when the targets are immediate neighbours to one another, as is typically the case in the toolbars, menus, icon-panels, and so on.

3 Experiment One: Is unaltered motor-space visual expansion profitable?

The first experiment investigates the comparative effectiveness of different forms of highlighting in aiding target acquisition. There is no motor-space enlargement in this experiment.

The participants' tasks involved selecting blocks of circular targets from the standard ISO-9241-9 multi-direction target wheel, as shown in Figure 3. The target wheel used constant amplitude of 512 pixels. Each selection involved moving across the target wheel to select the opposite item, as quickly and accurately as possible. The next target was identified by electric-blue colouring; all other items were grey. Successful acquisitions were indicated by changing the colour of the target to green for 500ms and unsuccessful acquisitions (clicking off the target's motor-space) caused the item's colour to change to red. Following either a successful or unsuccessful acquisition, the participants rested the cursor within the target, and after a delay of 500ms the next target was highlighted to prompt the next task.

The experiment was designed as a 2×2×4 repeated measures analysis of variance (ANOVA) for the following three factors:

- *Visual expansion*—on or off;
- *Mouse-over highlighting*—on or off;
- *Target width*—a diameter of 6, 10, 24, and 64 pixels.

When visual expansion was on, the diameter of the target doubled when the cursor entered the item's motor-space. The size of the motor-space remained unaltered. Figure 4 illustrates this behaviour as the cursor moves vertically across an item—note that in the two right-most images the target returns to its original size *before* the cursor reaches the visible edge of the expanded object. When visual expansion was off, the targets remained static.

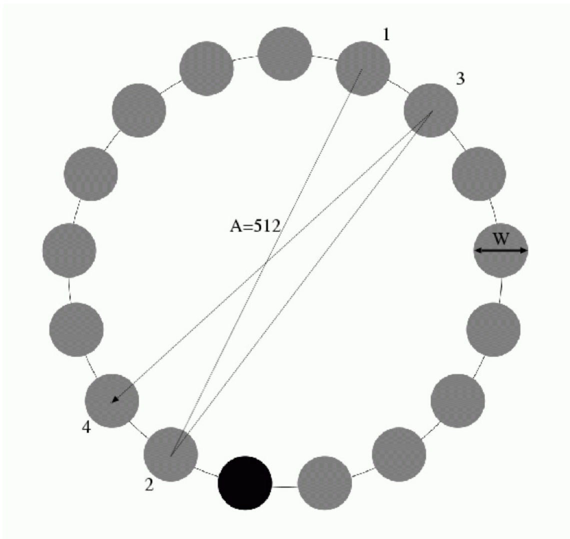


Figure 3. The ISO-recommended multi-directional tapping task.

When the mouse-over highlighting condition was on, the target's colour changed to navy blue when the cursor was over the item's motor-space. When highlighting was off, the targets' colour remained electric-blue while the cursor was over the target.

The dependent measures are target selection time (from the time that the cursor left the previous target to the time of correct selection), dwell-time (the time between entering the target for the last time and clicking the mouse button), and errors. Any mouse click that failed to hit a target was deemed to be an error, and the timing data for that selection was discarded.

3.1 Procedure

The tasks were administered in blocks of 17 acquisitions of identical width (6, 10, 24 or 64 pixels). The 17 targets consisted of one initial preparation task, then four selections for each of the four *visual-expansion*×*highlighting* combinations. Each of the 16 tasks was randomly assigned to one of the conditions, thus removing the participants' ability to anticipate target behaviour.

Each participant completed twenty blocks of tasks: four initial preparation blocks, with one block for each level of target-width, and sixteen logged blocks, with four repetitions for each level of target width. The order of exposure to each target width in the preparation and logged blocks was random.

Participants received no training or instruction regarding the behaviour of the targets. They were simply instructed to click on the items as quickly and accurately as possible.

3.2 Apparatus

The experiment ran on a Intel Pentium 4 2.8GHz computer running Fedora Core 3 Linux. Graphics were supplied by a GeForce FX5200 graphics card driving a 19inch Compaq monitor at 1600×1200 resolution, operating at 75Hz. Input was received through a Labtec three-button mouse, with a one-to-one control-display gain setting.

The multi-directional tapping task interface was written using the Java 1.5 API, and it ran full-screen.

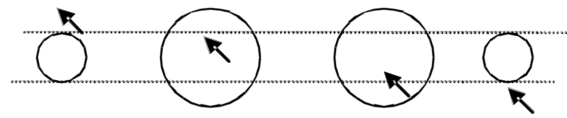


Figure 4. Detail of the behaviour of constant motor-space visual expansion. The visual width of the target doubles when the cursor is within the unaltered motor-space.

3.3 Participants

The 16 participants were all right-handed postgraduate Computer Science students (15 male, one female). The preparation and experimental tasks took approximately 25 minutes to complete.

3.4 Results

From the 4096 logged trial (16 participants, 16 blocks, 16 selections), there were a total of 175 incorrect selections, giving an error rate of 4.3%. Although not significantly different, there count of errors was higherwhen expansion was enabled, and also when highlighting was absent, as follows: no-expand, no-highlight 43 (4.2%); no-expand, highlight 36 (3.5%); expand, no-highlight 52 (5.1%); expand, highlight 44 (4.3%).

The main dependent-measure is total acquisition time. The overall mean for the 3921 successfully completed trials was 0.93s (sd 0.33). There was a significant main effect for factor *visual-expansion* ($F_{1,15}$=14.2, p<.01), with means of 0.917 (sd 0.31) with expansion and 0.945 (sd 0.35) without it. There was no main-effect for mouse-over highlighting ($F_{1,15}$<1, n.s.), with similar means of 0.928 (sd 0.33) for highlighting and 0.934 (sd 0.33) for none. As Fitts' law predicts, there was a strong main effect for target width ($F_{3,45}$=285, p<.01), with means ranging from 0.58s with 64 pixel targets to 1.33s with 6 pixel targets. Figure 5 summarises these results.

There was a significant *width*×*expansion* interaction ($F_{3,45}$=6.3, p<.01). Figure 5 shows the cause of the interaction, which is the performance benefit of expansion for the 6 pixel targets, in contrast to equitable performance for the other sizes. None of the other interactions were significant.

The dwell-time dependent measure is important because all the tested conditions are identical during the ballistic motion towards the target. The differences between conditions are only apparent to the user while the cursor is within each target's motor-space.

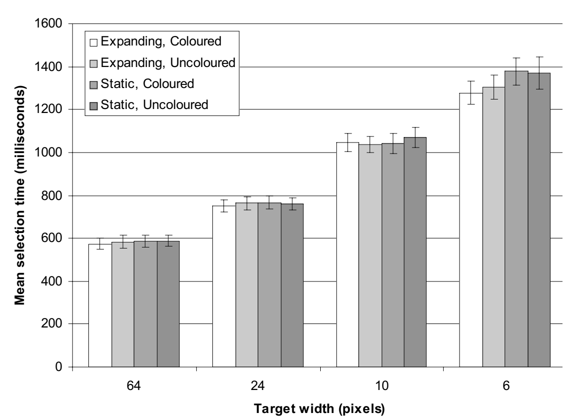


Figure 5. Mean target acquisition times in Experiment One. Error bars show mean ±1 standard error.

Dwell-time data shows significant differences for exactly the same main-effects and interactions as the total-time data. Dwell-times were lower with expanding targets (mean 0.156s, sd 0.07) than non-expanding ones (mean 0.165, sd 0.09): $F_{1,15}$=5.4, p<.05. The *width*×*expansion* interaction was significant ($F_{3,45}$=5.0, p<.01) due to expansion allowing reduced dwell-times with the smallest targets, but little difference for larger ones. The factor *highlighting* showed no significant main-effect or interactions.

3.5 Discussion

The main result is that visual expansion with unaltered motor space reliably improved target acquisition. Although the percentage performance improvement is small (approximately 6% for the smallest targets which have an ID of 6.4), it is surprisingly close to Zhai et al.'s improvement when using targets that expanded both visually *and* in motor-space: they do not directly report the percentage improvement, but Figure 6 in their paper suggests an overall difference of approximately 9% for ID=6.4, from 1080ms without expansion to 980ms with it. McGuffin & Balakrishnan showed an improvement of 12% from 1.178 with visual and motor expansion, and 1.335 without it, but their results cannot be directly compared with ours because their static and expanding conditions were administered in blocks that allowed participants to anticipate target behaviour.

Like Akamatsu & MacKenzie [2], we did not find a reliable performance advantage for highlighting in overall time-to-target, but while they did show reduced dwell-time with highlighting, our results did not replicate this finding. A probable explanation is that the main-effect for highlighting in our experiment incorporates both expanding and non-expanding conditions: the benefits of highlighting when expanding are likely to be masked by the stronger visual cue of expansion.

The findings of this study, then, lend support to the hypothesis that a substantial proportion of the benefits of motor-space expansion are due to the visual cue of expansion, rather than the enlarged motor-space.

4 Experiment Two: Comparing Visual and Motor Expansion

The second study directly compares acquisition performance using targets that expand either visually in unaltered motor-space or using enlarged motor-space. Static targets are also used as a control. Again, the multi-directional tapping task is used (Figure 3) with a constant movement amplitude of 512 pixels. All items in the target circle were coloured red, and the next target was identified using a black border. Task timing began when the cursor left the previous item, at which point the black border was removed to avoid any impact the border might have on the user's perception of the target as it expanded (or not). Successful target acquisition was depicted by placing a white border around the item, and having done so the next target was highlighted after the cursor had dwelt within its boundary for 500ms.

The experiment is designed as a 3×4 repeated measures analysis of variance (ANOVA) for the following factors:

- *Target-type*—static, visual, motor;
- *Target width*—a target diameter of 6, 12, 24, and 48 pixels.

'Static' targets remain unaltered when the cursor enters their motor-space, and their motor-space is exactly the same size as their visual appearance. 'Visual' targets double their diameter when the cursor enters their motor-space, but their motor-space is the size of their unexpanded state throughout (see Figure 4). 'Motor' targets are based on those used in the studies by McGuffin & Balakrishnan and Zhai et al.: when the cursor is within 51 pixels of the centre of the target (90% of the distance to

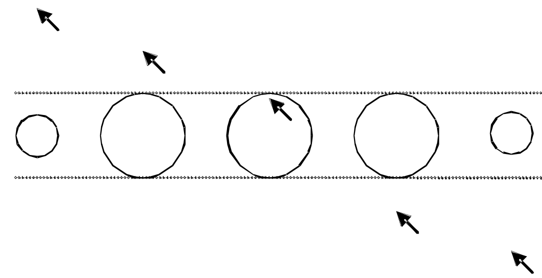


Figure 6. Enlarged motor-space expansion. The object expands when the cursor is within 51pixels of the object centre. The motor-space is continuously twice the unexpanded visual size.

it is complete), the target's visual size doubles to match the continuously enlarged motor-space. Figure 6 illustrates the behaviour.

The primary dependent measure is total acquisition time, which is also be used to derive Fitts' law models for the different target types. The second dependent measure is error rate, with any click outside a target's motor-space being deemed an error. The acquisition time data for tasks that contain an error are discarded.

4.1 Procedure

Like experiment one, the acquisition tasks were administered in blocks of 17 selections. Within each block, all targets were of the same visual size, representing one level of *target-width*. The first two targets in each block were of static-type, serving as preparation, and their data were discarded. The remaining fifteen selections consisted of five repetitions of each target-type, with a random distribution of target-types around the target-wheel locations.

Participants completed nine blocks of selections: an initial preparation block with a target-width of 24 pixels (data discarded), then two blocks for each level of target-width in a random order.

Participants were instructed to click on the targets as quickly and accurately as possible, and they were told that some of the targets would expand while others would not. The type and nature of the expansion was not described.

4.2 Apparatus

The hardware was identical to experiment one, except that the mouse was replaced with a Logitech cordless mechanical mouse.

The experimental interface was implemented using Tcl/Tk. It ran in a 700×700 pixel window.

4.3 Participants

The 15 participants were all right-handed male Computer Science graduate students and staff. The preparation and experimental tasks took approximately 10 minutes to complete.

4.4 Results

Across the 1800 trials, there were a total of 28 errors, giving an error rate of 1.6%: 10 with static targets, 12 with visual targets, and 6 with motor targets. Analysis of variance of error-rates shows no significant main-effect for target-type ($F_{2,28}$=1.0, p=.37), but there is a significant *target-type×width* interaction ($F_{6,84}$=2.8, p<.05), which is caused by static targets having a relatively flat distribution of errors across target-size in contrast to visual and motor expansion, which have few or no errors with large targets. There is an anticipated main-effect for target-width ($F_{3,42}$=3.1, p<.05), with errors increasing as the target size decreases—from

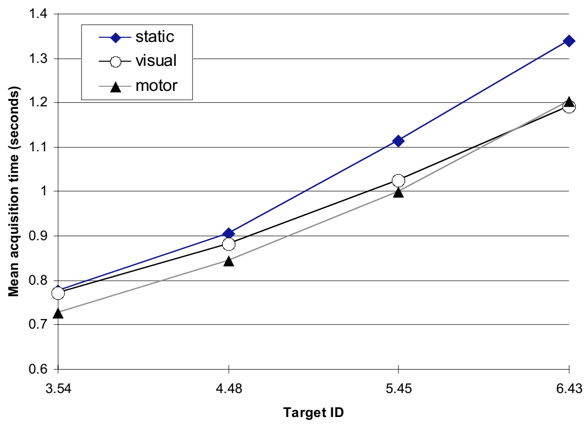


Figure 7. Mean acquisition times for static, visual and motor expansion across ID. The IDs represent target widths of 48, 24, 12 and 6 pixels respectively.

0.2% with 48 pixel targets to 2.7% with 6 pixel targets. Data from trials that included an error are discarded in the task-time analysis.

The mean acquisition time across all conditions was 0.981s (sd 0.24). As anticipated from experiment one, there is a significant main effect for factor *target-type* ($F_{2,28}$=12.1, p<.01), with static, visual and motor means of 1.033s (sd 0.26), 0.967 (sd 0.20) and 0.943 (sd 0.24) respectively. A planned pair-wise comparison between static and visual conditions shows a significant difference ($F_{1,14}$=20.8, p<.01), but a planned comparison of visual and motor conditions does not ($F_{1,14}$=1.7, p=0.2). Motor expansion improved acquisition times over static targets by an average 0.09s, but visual expansion in constant small motor-space accounts for 0.066s (73%) of this improvement.

As expected, there is a significant main effect for target-width ($F_{2,42}$=128.6, p<.01). There is also a significant *target-type×width* interaction, which is explained by the marked benefits of expansion with the smallest targets. Figure 7 summarises these results.

Regression analysis shows that the participants' performance with all target-types is accurately modelled by Fitts' law (see Table 1). To facilitate comparison with the other conditions, the *motor* condition is modelled using the ID of the unexpanded visual target-size, rather than its enlarged motor-space.

To help characterise the participants' ability to dynamically exploit the enlarged motor-space in the motor condition, we recorded the number of selections in the enlarged area. Of the 593 correct acquisitions in the motor-condition, 525 (89%) were made within the unexpanded motor-space. Only 68 selections were made within the enlarged area, with no clear trend across target size: the number of selections in the enlarged area with 6, 12, 24 and 48 pixel targets was 10, 15, 28 and 15 respectively.

Once each participant completed all of the blocks, they were asked to state how many different forms of expansion they had used, to describe them, and to comment on the experiment. Only three of the participants stated that there was more than one form of expansion, with one stating that "one form of expansion flickered" and two correctly stating that one form of expansion caused targets to enlarge before the cursor reached them. The comment about flickering is interesting because it captures the primary limitation of purely visual expansion: the targets are unexpanded *before* the cursor reaches their expanded visual edge. This effect might explain the comparatively high number of errors with visual targets (although the error analysis does not reveal statistically significant results).

Table 1. Fitts' law models for the three target types.

	Best fit, *MT=b×ID+a*	R^2
static	*0.197×ID+0.05*	0.99
visual	*0.145×ID+0.24*	0.99
motor	*0.164×ID+0.13*	0.99

5 Discussion

These results indicate that the visual effect of expansion explains much of the performance improvement previously identified with targets that expand in motor-space. In the second experiment, 73% of the performance benefit of enlarged motor-spaces was attained by visual expansion alone, and analysis of the location of selections showed that the enlarged portion of the motor-space was relatively seldom used. Furthermore, both types of expansion had the greatest positive impact with small targets (6 or 12 pixels, see Figure 7), yet the performance difference between visual and motor expansion with these sizes is small.

These results are good news for practical application of expanding widgets for two reasons: first, the range of potential application areas for visual expansion is much wider than that of motor expansion; second, visual expansion should yield most of the performance advantages of motor-space expansion, particularly for small targets. As Figure 2b shows, targets that visually expand to match an enlarged motor-space demand that the items be discretely arranged—they must be sufficiently separated to accommodate their expansion because, oddly, they are made to appear smaller than they actually are. This requirement for separation eliminates their applicability to many domains, including menus, toolbars, rulers, text, icon-panels, and so on. Visual expansion of the form shown in Figure 2a, however, can be used in all of these domains. 'Fiddly' small components such as margin markers, tabs, grab-handles, window-borders, and so on, could all realistically expand visually without any alteration in their motor-space.

These experiments raise many questions that we wish to examine in further work.

Discrete versus continuous targets. The current evaluations were confined to discretely arranged targets, but we intend to investigate the comparative efficiency of visual expansion with immediate neighbour targets, as shown in Figure 2a. To this end, we have begun evaluating a new form of 'Fisheye Menu' [5] (Figure 8). Preliminary results suggest that traditional menus and visually expanding menus allow very similar performance and that they both outperform the original Fisheye Menus by approximately 11%. These preliminary results are promising because they suggest that visually appealing 'cool' effects, which provide marketplace branding, can be supported without harming user performance.

Anticipation. We wish to investigate the differences between visual and motor expansion when users are able to anticipate the behaviour of the widgets. McGuffin & Balakrishnan tested their static and motor-expansion conditions in blocks that allowed anticipation, and Zhai et al. analysed both the presence and absence of anticipation. It is reasonable to predict that anticipation will allow increased performance with motor-space expansion because users will be able to aim less accurately, but it is unlikely to have a positive impact on visual expansion because users must target the same motor-space in the same traditional manner.

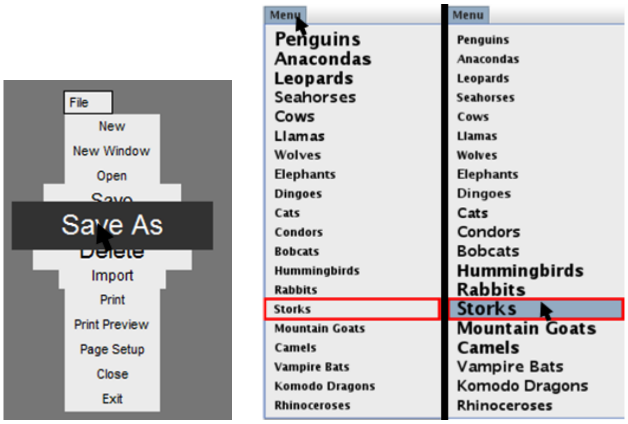


Figure 8. Two forms of fisheye menus based on visual object expansion. Left shows items visually expanding to occlude others, and right shows fonts enlarging to emphasise items near the cursor.

Systematic manipulation of ID and magnitude of expansion. The investigations reported in this paper tightly constrained several experimental parameters, including the amplitude of movement (512 pixels) and the magnitude of expansion (doubling the target size). In future work we will more completely examine the impact of varying these parameters. For example, increasing the magnitude of motor expansion should increase its effectiveness (the targets are larger), but it may harm visual expansion because the 'flickering' effect is likely to become more pronounced due to the increased distance between visual- and motor-space edges of each object.

Experiments with other forms of target and cursor feedback. We intend to examine other forms of visual feedback to determine how best to cue the over-target state. In experiment one, visual expansion out-performed highlighting with small targets, but it is reasonable to suspect that this performance advantage is partially explained by the cursor obscuring much of the highlighting effect with small targets. We wish to examine how different cursor representations influence performance, including smaller cursors that minimise occlusion and cursors that change their representation when over the target, as well as examining alternative ways of visually adapting the target.

6 CONCLUSION

Prior research has shown that targets that visually expand to fill an enlarged motor-space improve the performance of target acquisition, but it has few practical application areas because the space used for the expansion cannot be shared with other interactive objects. Curiously, enlarged motor-space expansion makes objects appear smaller than they really are. Visual expansion requires no additional motor-space—objects simply expand visually when the cursor is within their unaltered motor-space.

Previous experiments have attributed the performance improvements of enlarged motor-space expansion to the enlarged motor-space, yet experiments described in this paper suggest that for small targets much of this improvement is attainable by supporting visual expansion without enlarging the motor-space.

Users are particularly in need of assistance in target acquisition when trying to select very small items, and for this type of object the difference between performance with visual and motor expansion is small.

These results were produced in an experiment that used random exposure to the different forms of expansion, removing the participants' ability to anticipate target behaviour. They also used a fixed level of movement amplitude with discrete targets that expanded by a fixed magnitude. Future work will inspect the impact of anticipation and other experimental conditions, as well as exploring practical application of the techniques.

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